Simulation Studies on Silicon Detectors for a Vertex Spectrometer Upgrade of PHENIX at RHIC

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Outline

- **The PHENIX Experiment: Physics Goals + Baseline Detector Setup**
- **Measurement of Electromagnetic Probes**
- **Requirements for an additional Vertex Spectrometer**
- **Overview: Simulation Studies on a Silicon Upgrade**

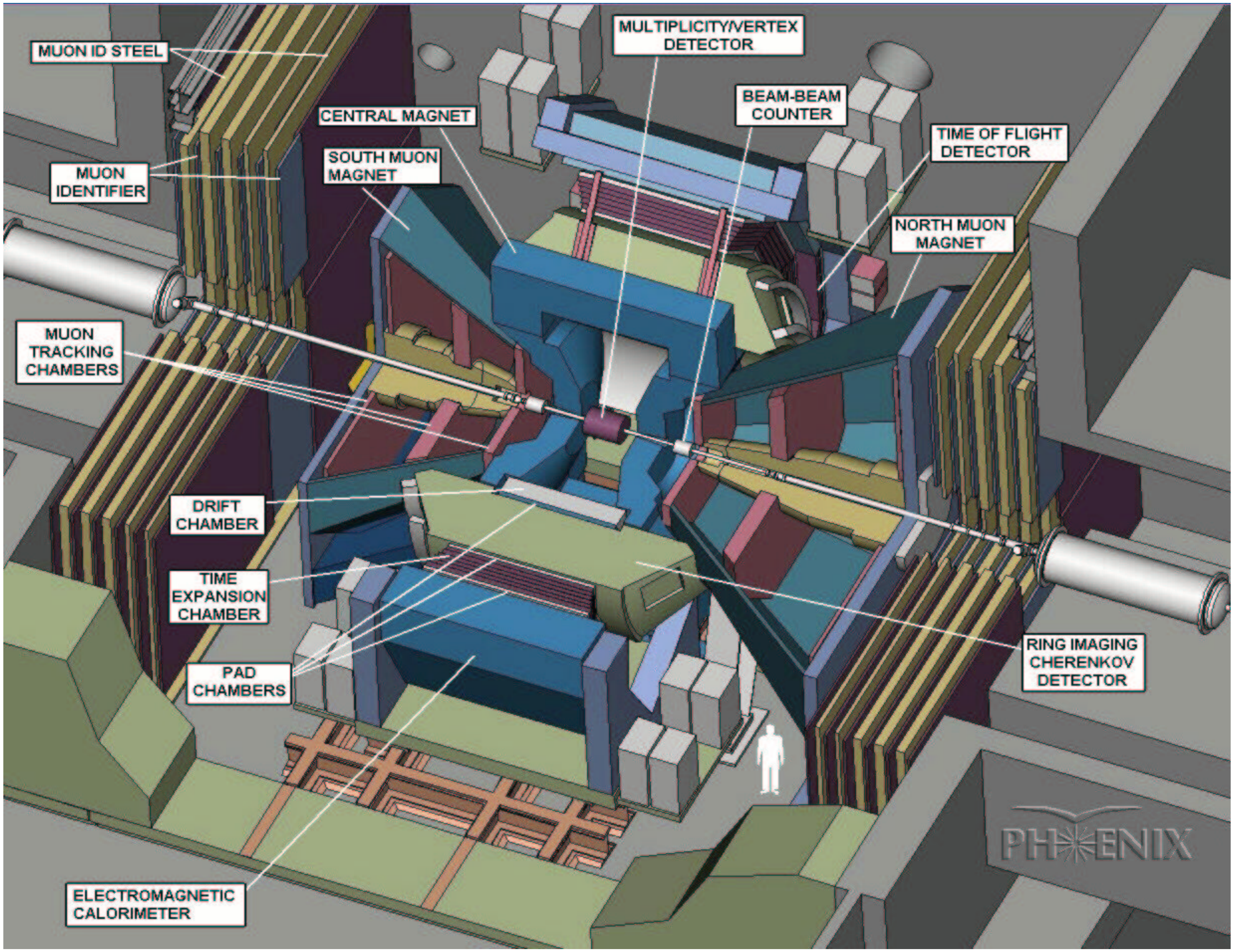
PHENIX Physics Goals

Relativistic Heavy Ion Physics:

- Detection of QGP state of nuclear matter in Au−Au collisions at $\sqrt{s}=200$ GeV/nucleon. Measurements of its properties.
- Access leptonic and hadronic probes in the same experiment.
- Electron pairs, muon pairs, e−μ coincidences, photons, charged hadrons.
  - Lepton pairs: probe the plasma directly (vector mesons, continuum spectra)
  - Photons: probe the initial phase via prompt photons
  - Hadrons: complementary info, hadronization phase transition

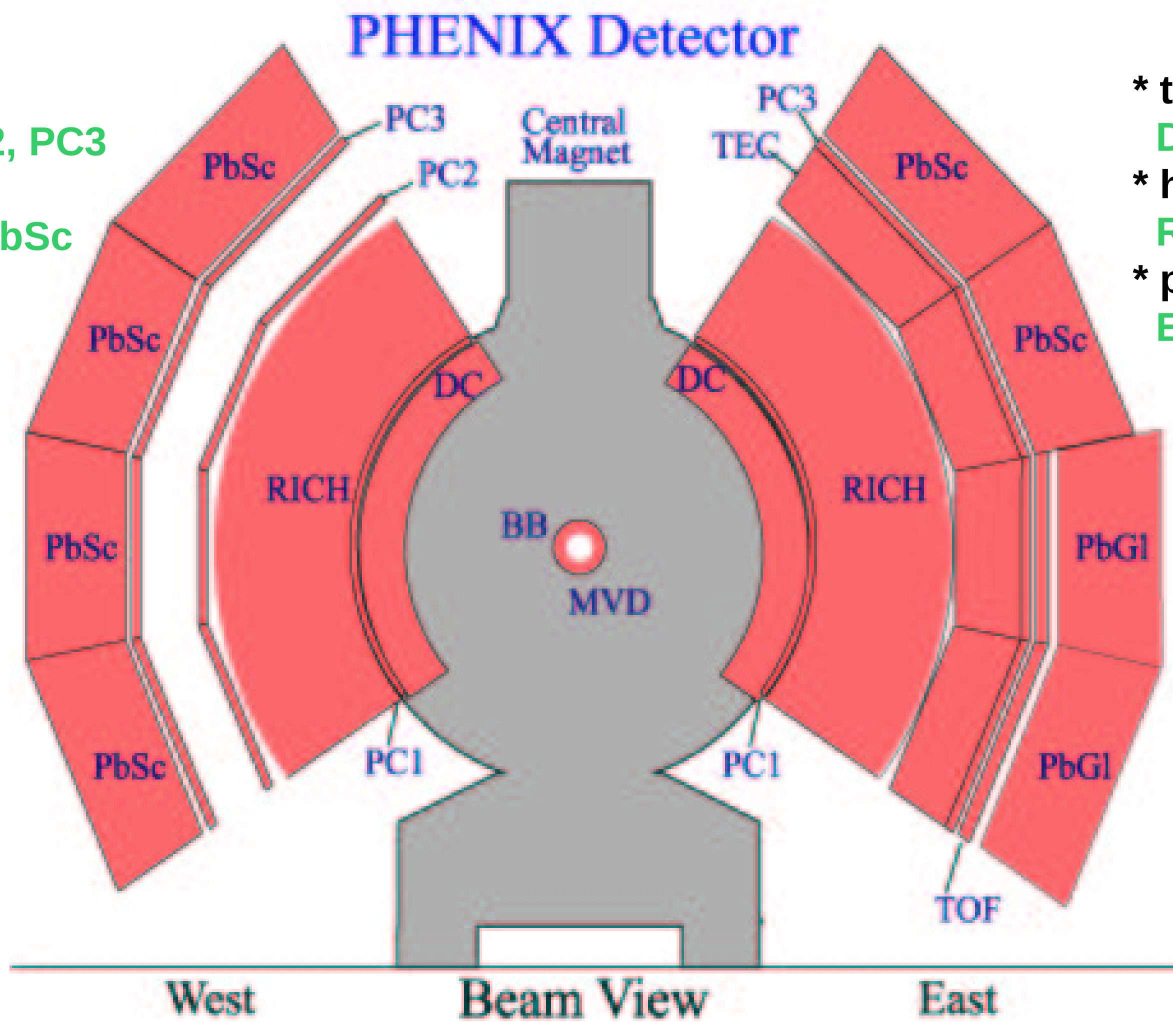
Spin Physics:

- Spin composition of proton.
- Collisions of polarized proton beams at $\sqrt{s}=200-500$ GeV.
- Main goal: measurement of the gluon polarization.
- Probes: high−p_t photon production, jet and heavy flavor production



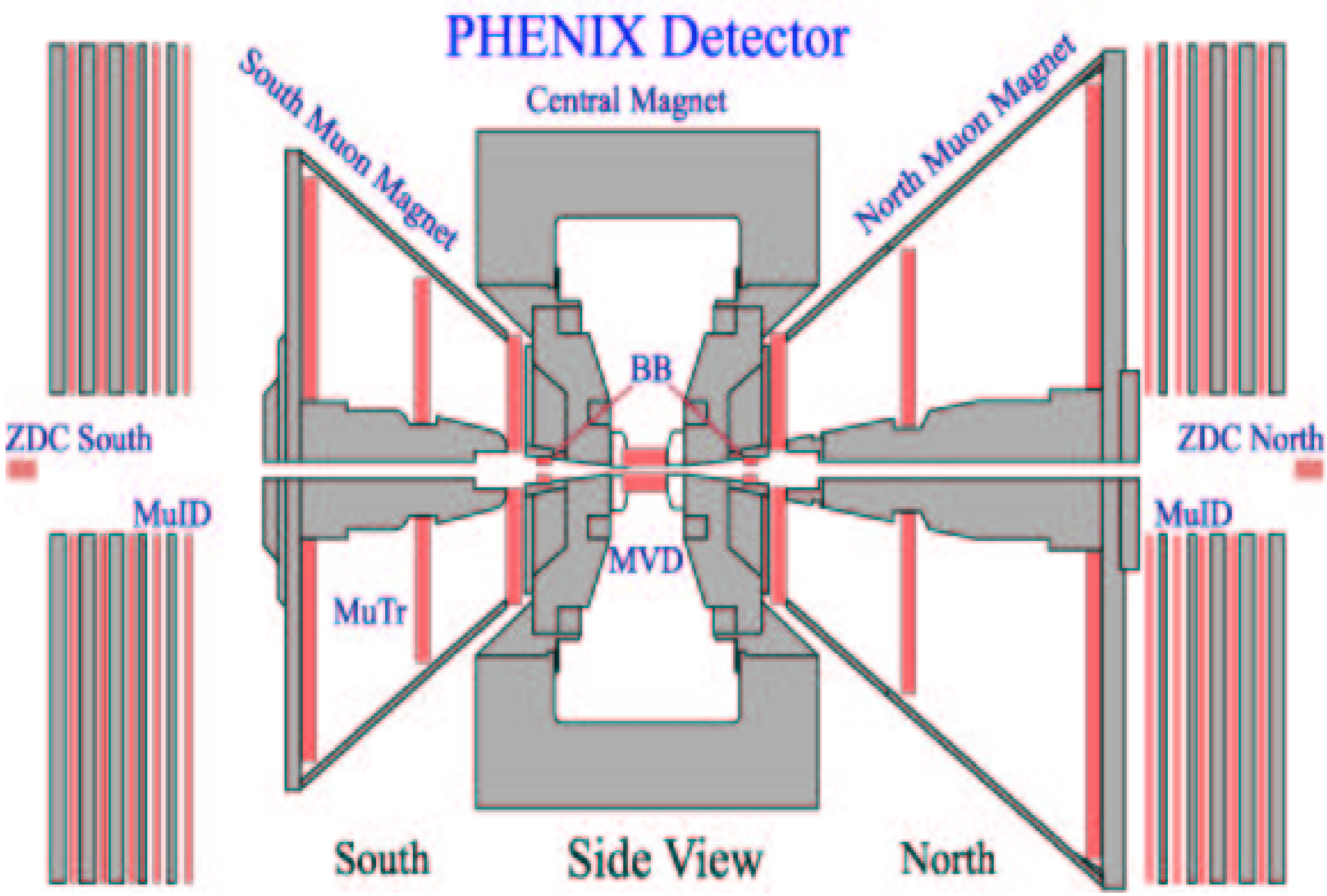
MUON ID STEEL
MULTIPLICITY/VERTEX DETECTOR
BEAM-BEAM COUNTER
CENTRAL MAGNET
TIME OF FLIGHT DETECTOR
SOUTH MUON MAGNET
MUON IDENTIFIER
NORTH MUON MAGNET
MUON TRACKING CHAMBERS
DRIFT CHAMBER
TIME EXPANSION CHAMBER
RING IMAGING CHERENKOV DETECTOR
PAD CHAMBERS
ELECTROMAGNETIC CALORIMETER
PHENIX

* tracking:
  DC, PC1, PC2, PC3
* electron id:
  RICH, EMC PbSc
* photons:
  EMC PbSc

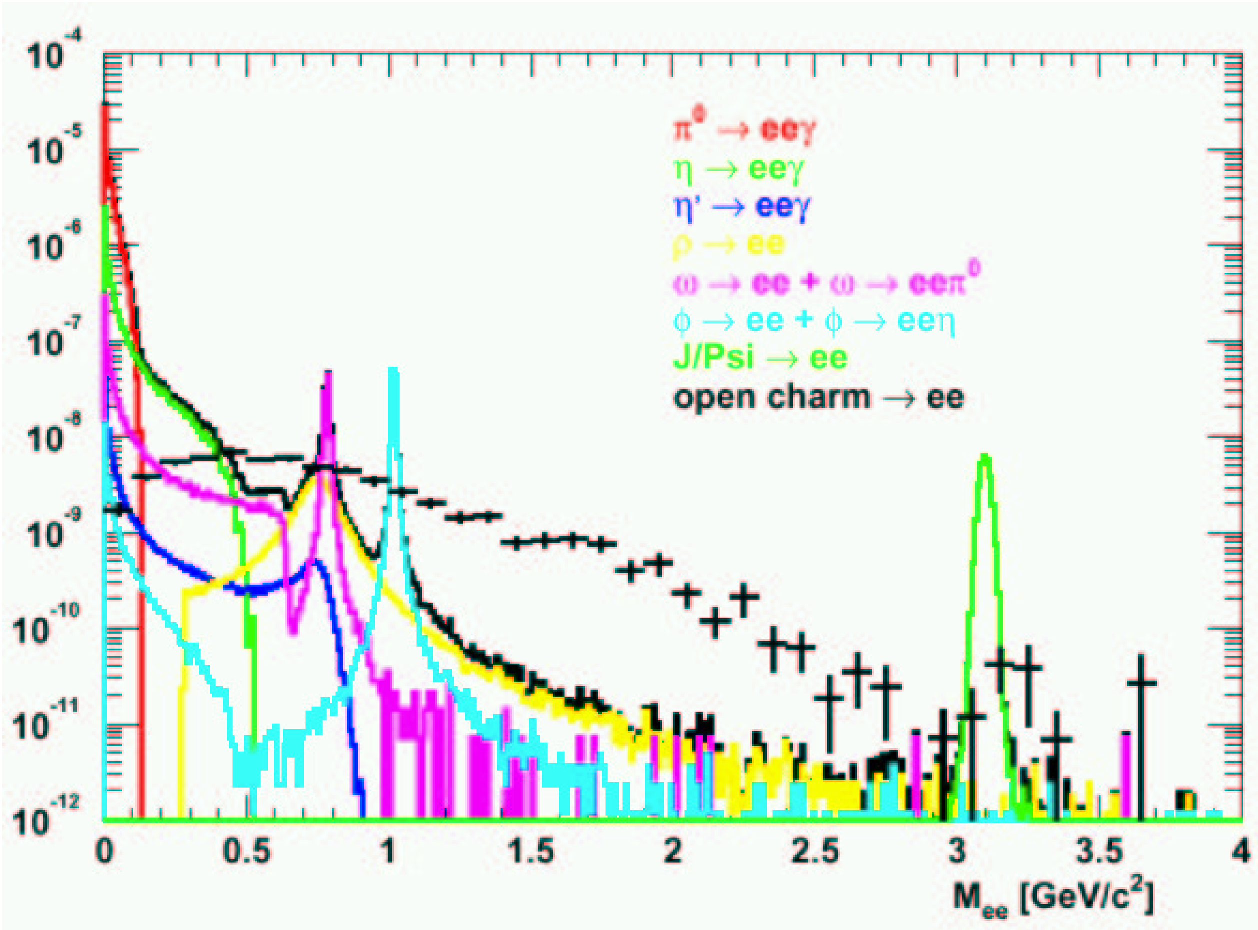


* tracking:
  DC, PC1, TEC, PC3
* hadron + electron id:
  RICH, TEC, TOF, EMC
* photons:
  EMC PbSc + PbGl

Vertex + centrality: ZDC, BBC, MVD


PHENIX Detector
Central Magnet
South Muon Magnet
North Muon Magnet
BB
ZDC South
ZDC North
MuID
MuID
MVD
MuTr
South
Side View
North

Central Arms: Electron Pair Measurement

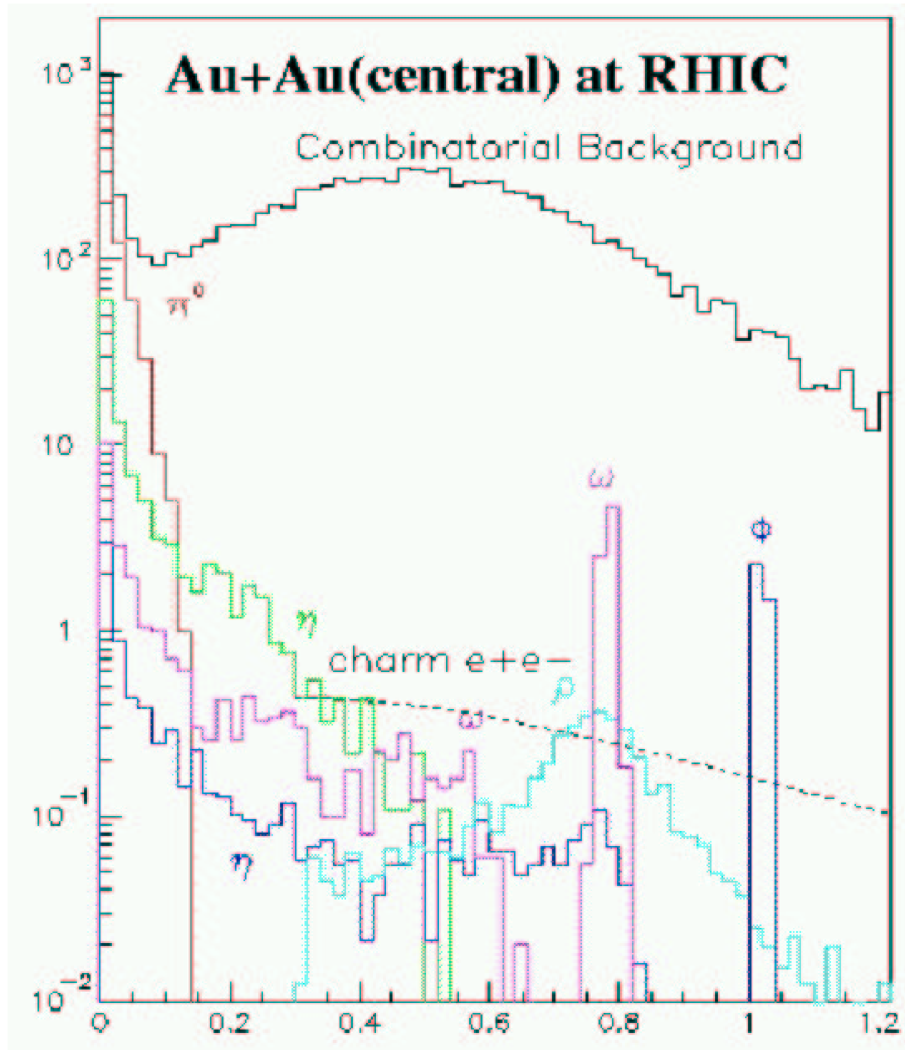


* resonances are addressed by PHENIX baseline setup (mass resolution!)

* continuum is not yet accessible: $\pi^0 + \eta$ Dalitz decays, open charm+bottom, Drell−Yan pairs

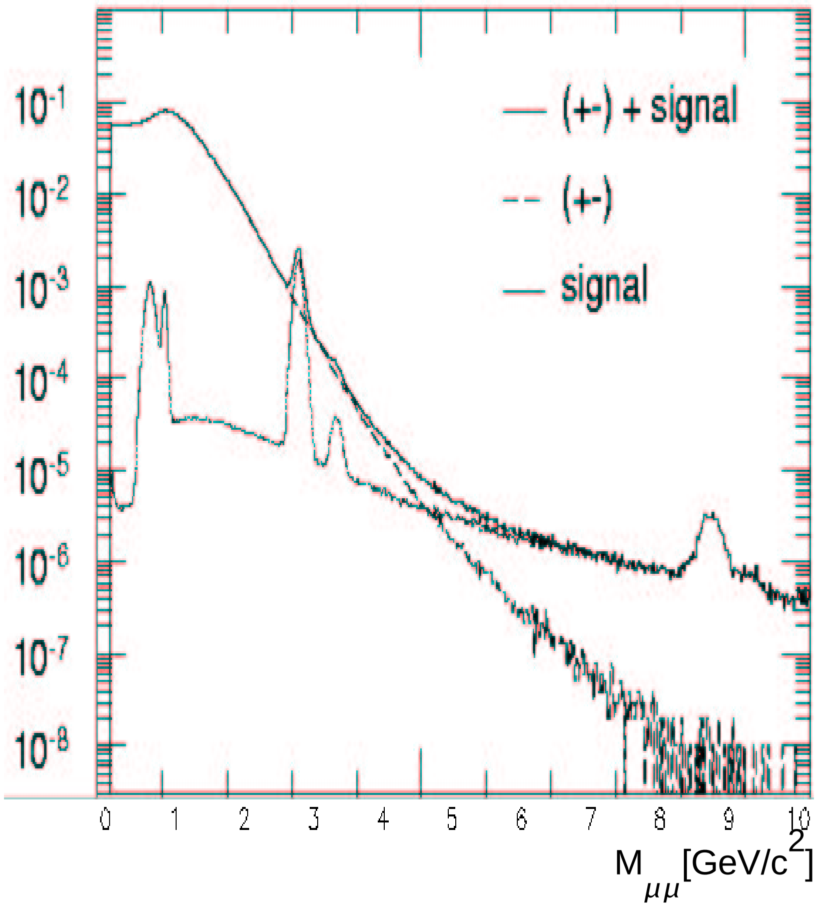
Background Pairs

- Electron background from Dalitz decays + photon conversions is significant! Exceeds low−mass signals by factors ~10−1000.
- Active background recognition and rejection of false pairs is required.
- Dalitz and conversion pairs: cut on small e^+e^- opening angle and small invariant mass.
  Limited Baseline, if both partners in acceptance and pass lower p_t cut.
- Electrons from charm and bottom decays: identification via secondary vertices. Not possible in Baseline. (MVD spatial resolution insufficient.)



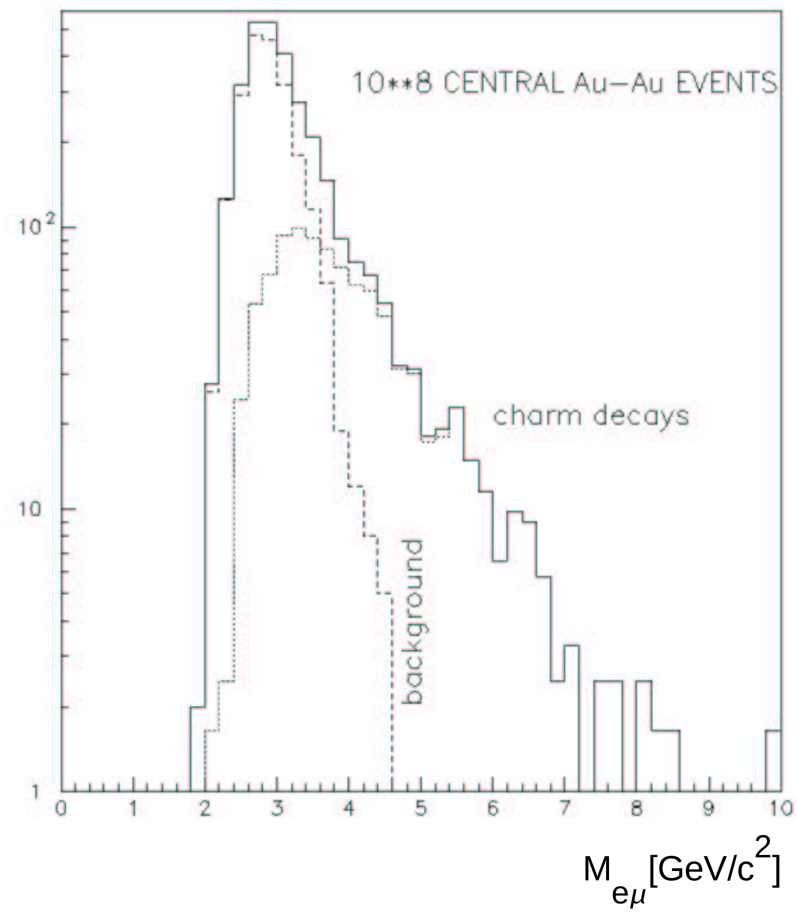
Forward Spectrometers

Di–Muon Measurement



* (sec.) vertex information: precision tracking in front of muon tracker.

Electron–Muon Measurement



* link from central to the forward spectrometers required, via vertex.

Upgrade with a Vertex Spectrometer

Requirements for a new detector 'subsystem':

Heavy Ion Program:

- tracking + electron identification (p_t > 200 MeV) over $\Delta\Phi = 2\pi$
- additional tracking at low momenta in field−free region to preserve opening angle of background pairs.
- secondary vertex reconstruction with $\sigma_{rms} \geq$ 30−50 μm, both in the central detector and the forward spectrometers.
- in high−track density environment: $dN_{ch}/d\eta|_{\eta=0} \leq 1000$

Spin Program:

- enhanced tracking acceptance $\Delta\Phi = \sim 2\pi, \Delta\eta = \pm 1.$
- precision vertex tracking (heavy flavor decay electrons, jet measurement)

→ **one multi−detector system,**
Vertex Spectrometer around beam pipe

Vertex Spectrometer Options

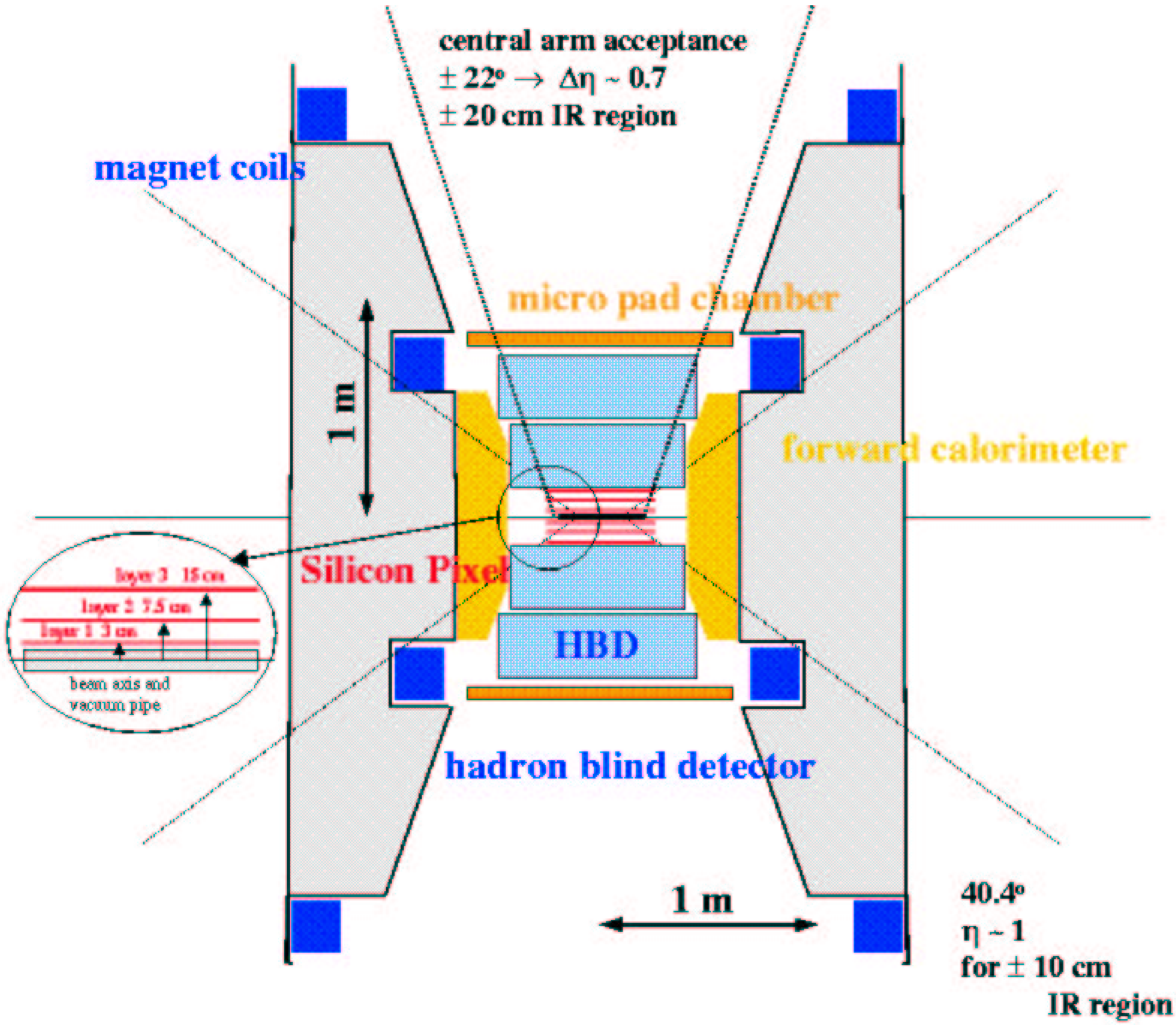
As discussed during a PHENIX Upgrades workshop (3/2001):

i) * 3−4 layers of silicon detectors
*** hadron blind detector (He−Cherenkov counter, CsI photo−cathode, GEM based readout)**
*** micro pad chamber (based on existing PHENIX PC)**

ii) * 1−2 layers of silicon detectors
*** combined with a Time Projection Chamber**

iii) a hadron blind detector and a TPC could share the same gas volume, combining options i) and ii) (⩽4 layers Si + TPC/HBD)

silicon detectors: micro−strips and pixels, barrels and end−disks



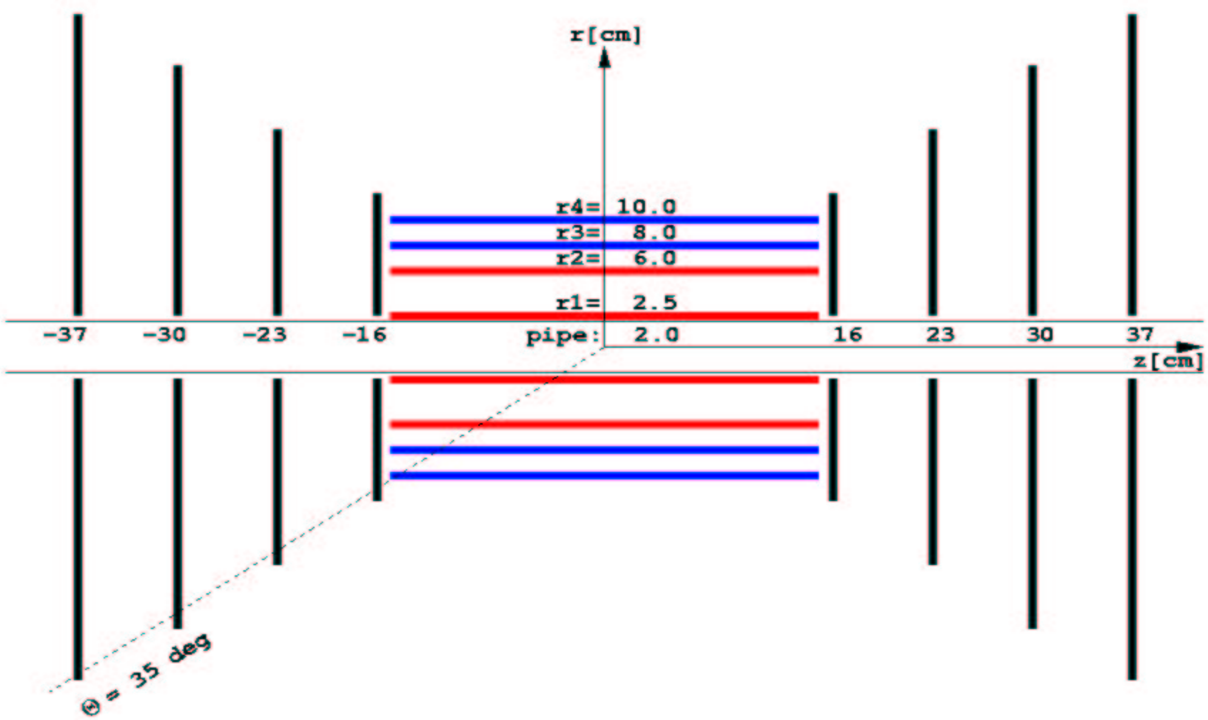
central arm acceptance
± 22° → Δη ~ 0.7
± 20 cm IR region
magnet coils
micro pad chamber
1 m
forward calorimeter
Silicon Pixel
layer 3 15 cm
layer 2 7.5 cm
layer 1 3 cm
beam axis and
vacuum pipe
HBD
hadron blind detector
1 m
40.4°
η ~ 1
for ± 10 cm
IR region

Silicon Detector Simulation Studies

PISA: PHENIX detector simulation software PISA:
Volumes implemented to enable studies on a new Inner Tracker.

Geometry: A **c**oncept was defined to address enhanced measurements with the central + forward spectrometers in heavy ion and spin physics.

Assumption: 1% X/X_0 per silicon layer; 500μm Be beam pipe.



* pixel barrels
* strip barrels
* pixel disks

Silicon End Disks

* Provide **additional vertex tracking for the muon spectrometer**, in front of the central magnet poles.

* Interesting processes for which vertex tracking is required:

$\mathbf{D} \rightarrow \mu\, \mathbf{X}$, $\mathbf{D} \rightarrow \mu\, \mathbf{hX}$, $\mathbf{J/}\psi \rightarrow \mu\mu$

* Achieve tracking with: **4 pixel disks**, covering polar angles ~10 − 35 deg.

* Measurement of: − impact parameter ($r\Phi$)
  − z−vertex

* Perform tracking with: a) end disks only, and in limited region:
  b) end disks tracks + two inner barrels.

* Studies indicate: − Impact parameter (pointing) resolution ~100μm, assuming a pixel size of 50μm x 200μm.
  − Decay vertex resolution ~160μm.
  − Both dominated by multiple scattering.

Pixels essential for 3−dim sec. vertex finding, momentum/ charge determination, and handling of the occupancy (<1% in 1st disk).

Silicon Strip Barrels

* **Silicon strip detectors:** discussed as a first step of the Inner Tracker upgrade, mainly to be used in a **pp environment**.
  Tracking for jet and heavy flavor decay electron measurement.

* Study to investigate the limitations for an application to heavy ion collisions.

  − has been performed for a different geometry than outlined before:
  4 layers of 100μm x 5cm strips: r1 = 5.0 cm
  r2 = 10.0 cm
  r3 = 12.5 cm
  r4 = 15.0 cm

  −HIJING generator, track matching to Pad Chambers, selection of events with sufficiently isolated hits in the silicon:

  −**occupancies:** 25% 1st layer, 10% 2nd layer, 7% 3rd layer, 5% 4th layer.

* investigate revised geometry, and with pixel rather than strip option for 1st/2nd layer.

Silicon Pixel Barrels

challenge: * Tracking in high track density environment, close to beam line.
$\rightarrow$ Pixels provide unambiguous space points.
Spatial resolution of a few tens of μm natively achievable.

main issue: * Multiple scattering in first detector layer strongly affects secondary vertex measurement for open charm **$D \rightarrow eX$,**
open bottom **$B \rightarrow eX$.**

* Decay lengths $c\tau$ [μm]: $D^{\mathbf{0}}$: 125 $D^{\pm}$: 317
$B^{\mathbf{0}}$: 464 $B^{\pm}$: 496

* No Lorentz boost transverse to the beam!!

* Can a sufficient background rejection be achieved with a realistically thin detector?

strategy: * place 1st silicon layer as close as possible to the beam: 2.5cm.

* assume already reduced beam pipe radius of 2.0cm.

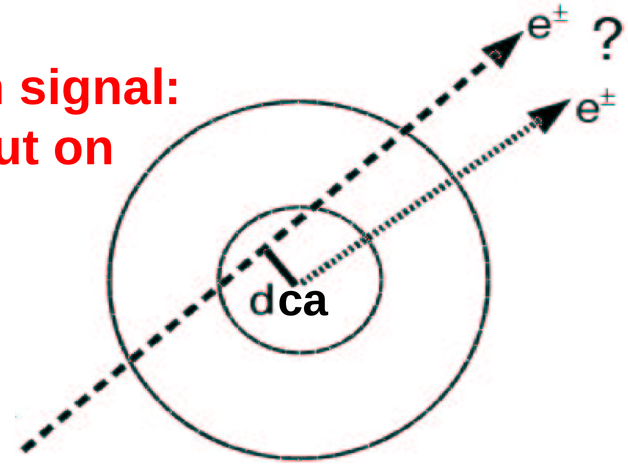
* here: $r\Phi$ measurement only (for 50μm x 425μm pixels existing);

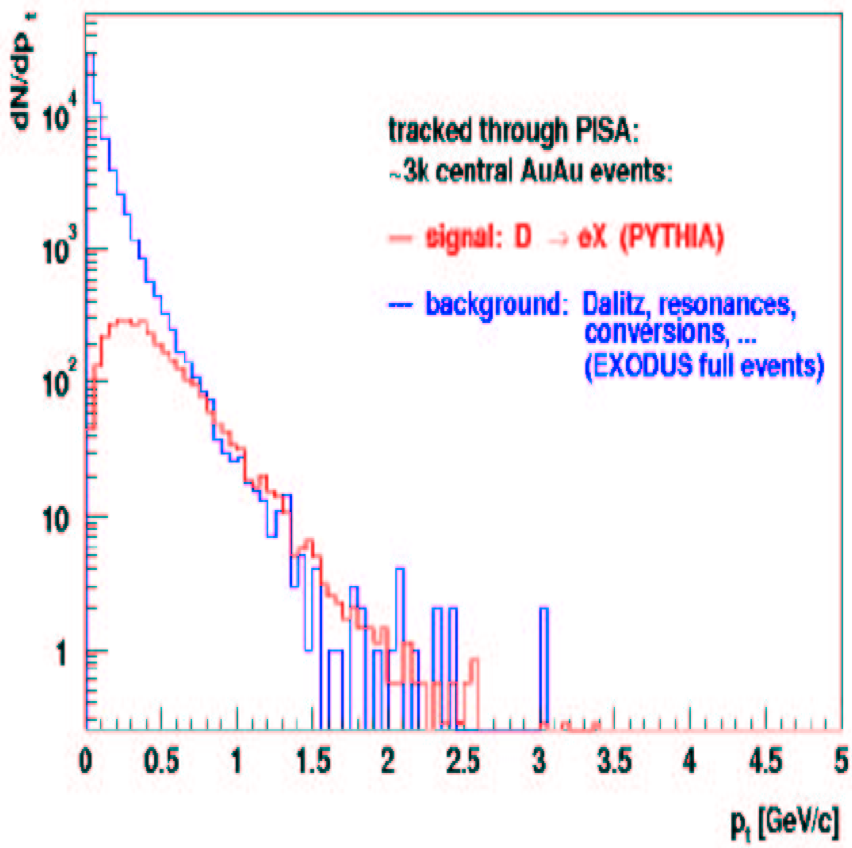
$\rightarrow$ study applies to pixels and micro strips alike at this time.

Silicon Pixel Barrels II

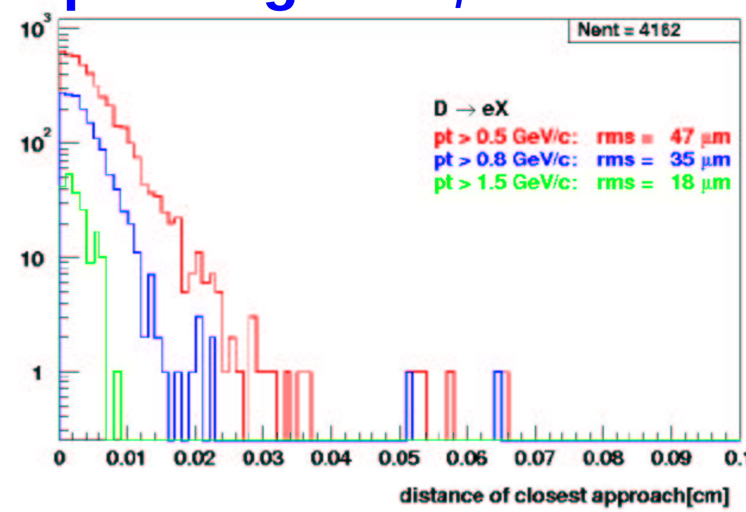
Signal D$\rightarrow$eX and background:

Find secondary vertex from signal: tracking in rΦ projection, cut on distance to event vertex.



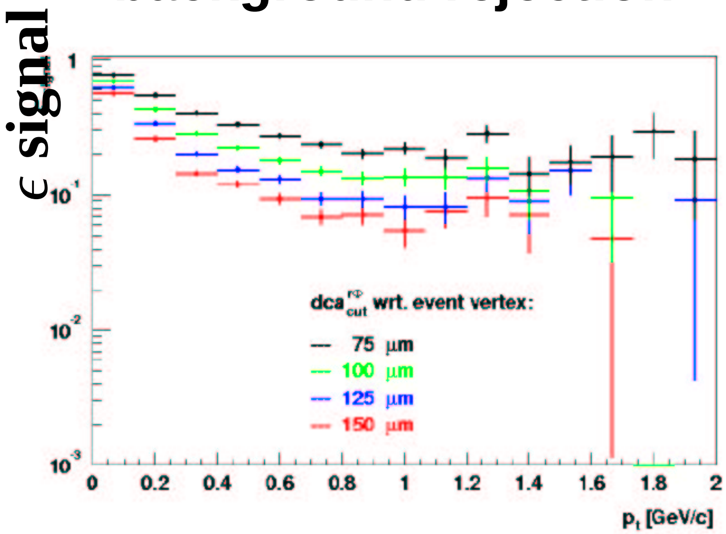


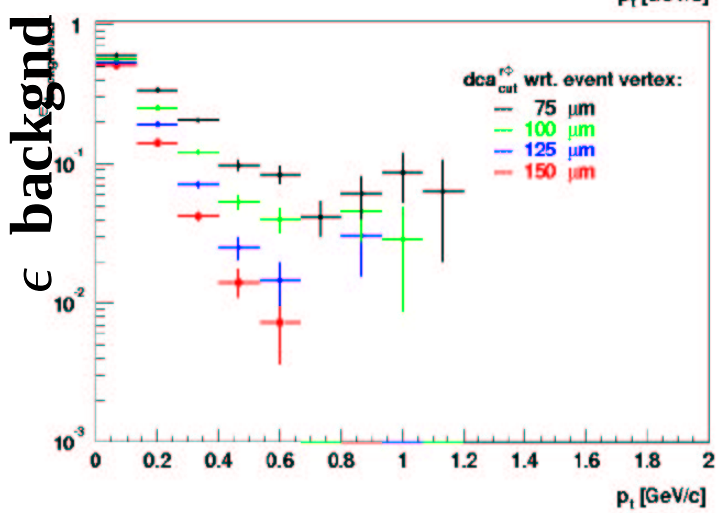
pointing: $\approx$ 35μm rms



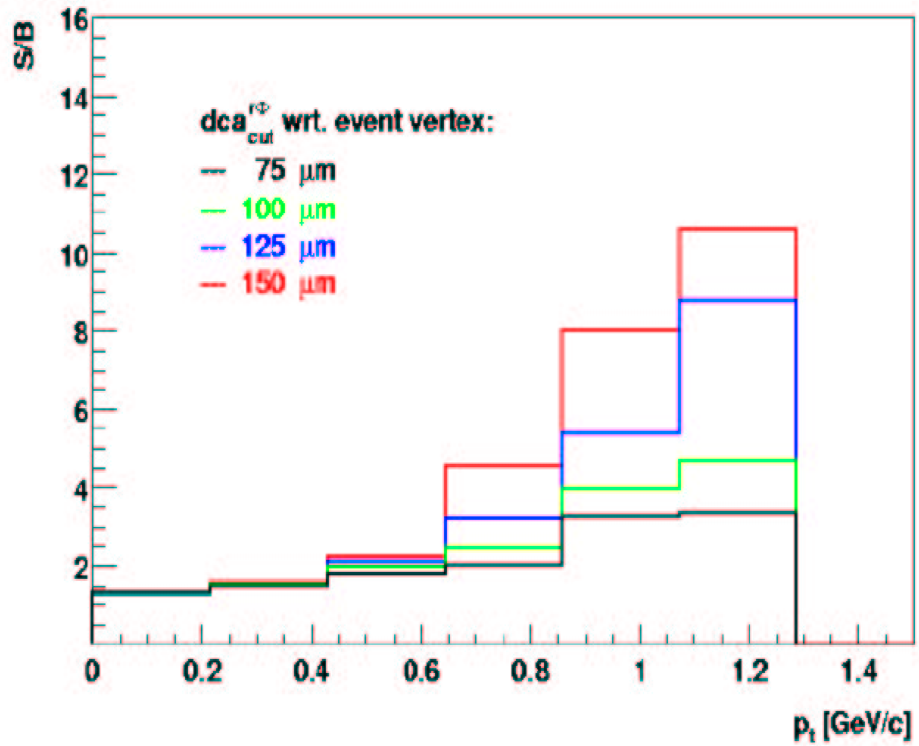
Silicon Pixel Barrels III

signal detection and
background rejection





signal−to−background ratio
in 0.3mm Silicon (~0.3% X/X_0)



* distance cut of ~100μm accesses the signal.

* repeat D study for B * pair study * real events

* **optimize thickness!!! Max. tolerable material?**

Summary

PHENIX: the large experiment at RHIC that emphasizes the measure–ment of rare electromagnetic probes.

- Lepton pairs as direct probes of Plasma: Vector mesons, continuum
- PHENIX – central spectrometers: electrons + photons.
  – forward spectrometers: muon measurement.
  – baseline design: aims at the resonances.
- Requirement for a new vertex spectrometer:
  - combinatorial background: Dalitz + conversion pairs
  - open charm/bottom contribution: e, μ
  - then: continuum accessible
  - furthermore: RHIC Spin program + precision vertex tracking

A concept for such a PHENIX upgrade was presented, consisting of silicon tracking detectors as the innermost components. Simulation studies were started up to explore the capabilities and feasibility of the arrangement.

Work in progress was overviewed – more to come for the RHIC Upgrades Workshop 11/2001.